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# Analysis of the impact of energy efficiency labelling and potential changes on electricity demand reduction of white goods using a stock model: The case of Switzerland

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## HIGHLIGHTS

- Develops a method to calculate household appliance stock and electricity demand.
- Shows forecasting of appliance stock and electricity demand for the next 20 years.
- Calculates cost-effectiveness and payback period for appliance replacements.
- Shows the impact of new technologies and energy labelling/standard of appliances.
- Shows detailed comparison of different scenarios to achieve energy demand reduction.

## ARTICLE INFO

*Keywords:*
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## ABSTRACT

This paper presents the development and application of a dynamic model which allows to quantify the changes in the number of white goods in stock, the related evolution of energy efficiency as well as the changes/projections of electricity consumption in the next 20 years using data from Switzerland. According to the "reference scenario" based on observed market trends the electricity demand of white goods is expected to decrease by 8% between 2015 and 2035. The analysis shows that this is the combined result of having more energy efficient appliances in the stock, a higher appliance ownership level, and an increased number of dwellings. The "maximum efficiency" scenario based on new technologies shows an electricity saving potential of white goods of 25%. These findings confirm that energy efficiency standards and labelling can be effective instruments for achieving energy and $CO_2$ emissions reduction targets. The assessment for cost effectiveness indicates the current limited scope for economically viable energy efficiency improvements of white goods, while novel technological solutions are likely to expand the economic energy efficiency potential. Since white goods and their components are mass-produced and traded internationally, similar findings can be expected for other countries with comparable legislation (e.g. EU member states) but country-specific analyses are nevertheless recommended.

## 1. Introduction

The implementation of energy efficiency (EE) measures is considered as key strategy for reducing non–renewable energy consumption and $CO_2$ emissions in Switzerland and globally [1,2]). The annual electricity consumption of Switzerland has remained steady in the range of 58–60 TWh since 2010 [3], of which approximately one third was consumed by households. White goods (i.e., dishwashers, washing machines, tumble dryers, refrigerators, freezers and cooking appliances) accounted for approximately one third of the total household electricity consumption in 2016 [4]. In order to increase the efficiency of these electrical appliances, many countries across the globe have introduced mandatory energy efficiency labelling requirements for appliances [5]. In the European Union, energy efficiency labelling is subject to Regulation (EU) 2017/1369 [6] while minimum energy performance levels are specified by the Ecodesign directive [7,8]. In Switzerland, an Energy Efficiency Directive (EnV 730.01, 1998R) was implemented which specifies both minimum energy performance and

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energy labelling (in line with EU legislation) [9]. For a number of household appliances, Swiss minimum energy performance standards are stricter than in the EU, making Switzerland a forerunner in this domain [10].

As a consequence of these regulatory measures, the average energy efficiency of the household appliance stock can be expected to be improving. However, according to the Odyssee project database [11], electricity consumption per dwelling for household appliances (without cooking) in EU-28 increased by 0.29% p.a. from 2000 to 2016 (by 1.2% p.a. for the total electricity consumption). France, Denmark and Germany were the countries which achieved the highest energy efficiency improvement (0.2–0.3% p.a. on average) for this appliance group were while the energy efficiency deteriorated for Poland, Spain and Lithuania (1.3–3.3% p.a. on average) [11]. While the progress made in energy efficiency has hence been significant for some countries, the increasing number of appliances raises the question about the evolution of electricity use and its further course. Therefore, it is important to understand what the main drivers are for electricity consumption and for the future dynamics of household electricity consumption. Such insight can help to design and implement effective policies to enhance energy savings related to household appliances and to reduce $CO_2$ emissions from the residential sector.

There are only very few scientific studies analysing and projecting the electricity use for household appliances in Europe [12,13,14] and Switzerland [15]; [16,17]. Mentioned reports mostly offer insight into consumption dynamics but provide scarce information on the evolution of key parameters and assumptions made in model construction. REMODECE (2008) estimates the national savings by calculating the difference between the energy consumption of the present state of the country and energy consumption by combined application of best available technology and best practise, however without unravelling these two factors. Also, they do not offer any forecasting and their analysis covers only the period from 2002 to 2008. Surveys on appliance ownership could provide important insights into the appliance stock over the years but nation-wide surveys are conducted very seldom (e.g. in 2005 and 2011 representative of Switzerland; in 1994, 2005, and 2011 in UK). Other studies focus only on the identification of the impact of appliance types on the electricity consumption of households; and they typically do not provide an assessment on new technologies, systems or practises [18–21]. Finally, the International Database of Efficient Appliance (IDEA) collected by LBNL is quite rich in data (designed to be regularly updated), however it is limited to the year for which the data is collected; it therefore only provides present-day market comparisons which are not sufficient to recommend any specific policy actions or to predict their impact [23].

To address these limitations, this paper describes the development and application of a stock model that allows quantifying the changes in the number of appliances in stock, the related evolution of energy efficiency, as well as the changes/projections of electricity consumption between 2000 and 2035. The bottom-up stock model calculates the energy consumption based on energy efficiency label of each appliance type that allows the users to evaluate the impact of different energy efficiency labels and new technologies as high level of detail which is an important add-on compared to other studies on the same topic, which are based only on end-uses. The design of a consumption model involves translation of efficiency labels into representative energy consumption values, information about user behaviour and modelling the life expectancy of appliances. A key strength of our method, as opposed to previous studies, is that it combines existing methods to calculate the current appliance stock with modelling of future changes in the household appliance stock by projecting sales as well as lifespans using a Weibull distribution. In addition, we provide detailed analysis of cost-effectiveness for failure replacement.

The analysis focuses on white goods, including cold appliances (refrigerators and freezers), wet appliances (dishwashers, washing machines, tumble driers), and cooking appliances (ovens and stovetops). White goods account for almost 50% of the total electricity consumption of electrical appliances in Switzerland [2]. Electricity demand for lighting in Swiss households was recently covered by a paper by Heidari et al. [24] and consumer electronics is covered by a separate publication (in preparation). A large number of datasets are used to develop the stock model which range from (i) ownership levels of various appliance types in Swiss households; (ii) annual sales; (iii) representative usage data of appliances; (iv) empirical lifespan data including obsolescence probability data; (v) outflow of waste appliances; (vi) energy consumption by appliance type and label classes); (vii) minimum standards for consumption; and (viii) price data for different efficiency categories. The model is then applied to project future electricity consumption and assess the electricity consumption reduction potential under two different policy circumstances – 'business as usual' and 'efficient technology'. Apart from stock and energy demand projections, the paper also presents a comparison of cost effectiveness of efficiency improvements for white goods. In-depth analysis and bottom-up modelling of household electricity consumption is not only of relevance for policy making, it also raises pressing questions about the methodological approach and data aspects and the robustness of the results which are of general scientific interest.

The paper is structured as follows: Section 2 presents the background and existing literature on Swiss electricity consumption, appliance demand, and methods for analysing household appliance consumption. Section 3 presents the chosen methods, covering the stock model, consumption model, and cost effectiveness calculation. Section 4 presents the results of the stock model and electricity demand of household appliances, including the cost effectiveness of appliance replacement. The findings are discussed in Section 5 and conclusions are drawn in Section 6.

## 2. Background

### 2.1. The trends of household electricity consumption in Switzerland

Electricity demand in Swiss households increased by 10–15% from 2000 to 2015 according to De Haan et al. [25] and Kemmler et al. [17]. Past growth in household electricity demand has been driven by population and increased wealth (GDP) [26], which rose by approximately 10% and 20% between 2003 and 2013, respectively. According to the Swiss Energy Strategy 2050 the total electricity demand of households is projected to decrease by 5%, 15%, and 17% from 2010 until 2035 in the three scenarios 'business as usual', 'political measures', and 'new energy policy' [16]. Yearly electricity consumption *per household* is expected to drop by 21%, 30%, 31% in the three scenarios, respectively. (Table 1). This is caused by energy efficiency

**Table 1**
Annual consumption of electricity per household in kWh, hh: household, y: year [16].

| | 2000 | 2010 | 2020 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|---|---|
| Number of households in 1000 | 3144 | 3545 | 3962 | 4207 | 4274 | 4323 | 4384 |
| Business as usual [$kWh_{el}$/hh/y] | 5001 | 5250 | 4529 | 4226 | 4147 | 4093 | 4062 |
| Policy measures [$kWh_{el}$/hh/y] | – | – | 4466 | 3882 | 3685 | 3573 | 3447 |
| New energy policy [$kWh_{el}$/hh/y] | – | – | 4480 | 3876 | 3633 | 3425 | 3067 |

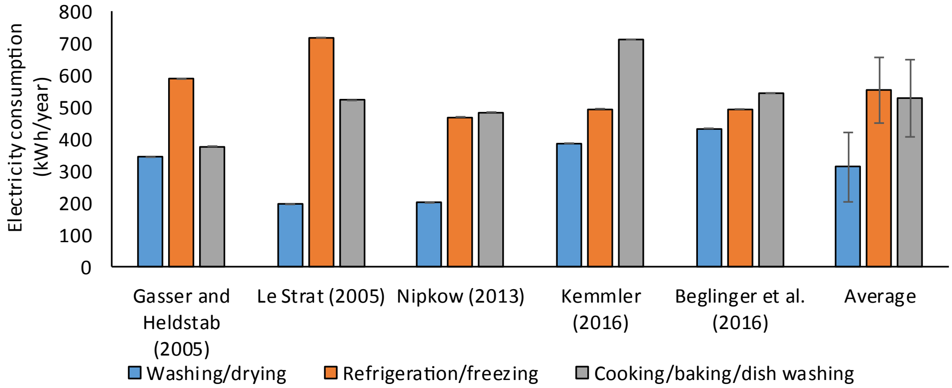


**Fig. 1.** Household electricity consumption (kWh/year) by appliance group of white goods and resulting average with standard deviation.

improvement and the increasing number of smaller households [16].

### 2.2. Swiss household appliance electricity demand

The electricity consumption of the white goods that are washing/drying, refrigeration/freezing and cooking, as well as dishwashing for an average household differs substantially (29% deviation) according to the five sources summarised in Fig. 1 (described in detail in Appendix A). Since the breakdown of energy use by application differed substantially in the original sources (e.g., 'electricity for refrigeration only' vs. 'electricity for refrigeration and freezers'), we aggregated to a level that is shared by all. When comparing and interpreting the values it should be kept in mind that some of the sources date further back than others and that the electricity consumption per household has changed significantly through the years (as an illustration it grew by 20% between years 2000 and 2010, page 263 of Kirchner et al. [16]. On average, cold appliances are the highest electricity consumers, followed by kitchen appliances (including cooking and dish washing), and washing/drying (Fig. 1). It is plausible that the data for cold appliances are the most consistent since their operation depends less on usage. The displayed data for kitchen appliances could be affected by the fact that natural gas is also used as cooking fuel besides electricity (although in decreasing quantities). Swiss multi-family houses are typically equipped with a shared washing machine and shared tumble driers, even if this is gradually becoming less common (according to our calculations of appliance ownership using the surveys of VSE [27] and VSE [28]. The fact that electricity demand of shared equipment is not assigned to individual apartments may explain the relatively low values for this energy service, especially in older studies (see Fig. 2).

Since the increased energy efficiency could potentially be counteracted by the increase in the number of households and/or intensified appliance use, it is essential to obtain deeper insight into total energy use for appliances in Switzerland. Total electricity consumption for both Swiss household appliances and white goods indeed increased between 2000 and 2015 [29,17]; however, no information is available on the contribution of the various underlying factors.

### 2.3. Applied methods for household appliance stock and electricity demand estimation

Policy makers require accurate estimates of household appliance electricity demand as an input for their environmental strategies. Several methods have been applied to improve the understanding of how electricity is currently used in households and to predict future electricity consumption. These methods include:

**Bottom-up surveys:** collecting information on appliances from individual households via surveys. Then, the appliance stock is converted to energy consumption by using the average power of the appliance taken from technical reports [30–31]. However, these surveys are rarely conducted, and available studies do not provide enough data points for forecasting. Moreover, simple extrapolation using few data points for the ownership levels may cause significant errors. The last time this kind of survey was carried out in Switzerland, UK, France and Germany was in 2011, 2011, 2009 and 2009, respectively. These surveys have also been used to identify the effect of individual appliances on the domestic electricity consumption and to study the effect of energy efficiency labels using regression analysis [18–21]. However, these studies do not assess new technologies, practises and they hardly evaluate policies targeting energy savings or emission reduction while primarily identifying the determinants of electricity consumption.

**Monitoring:** recording the electricity consumption of appliances via plug-in meters. They give a real picture of the energy consumption performance of the appliance [33–35]. Since monitoring is expensive the limitation of these studies is that they typically only concern a small

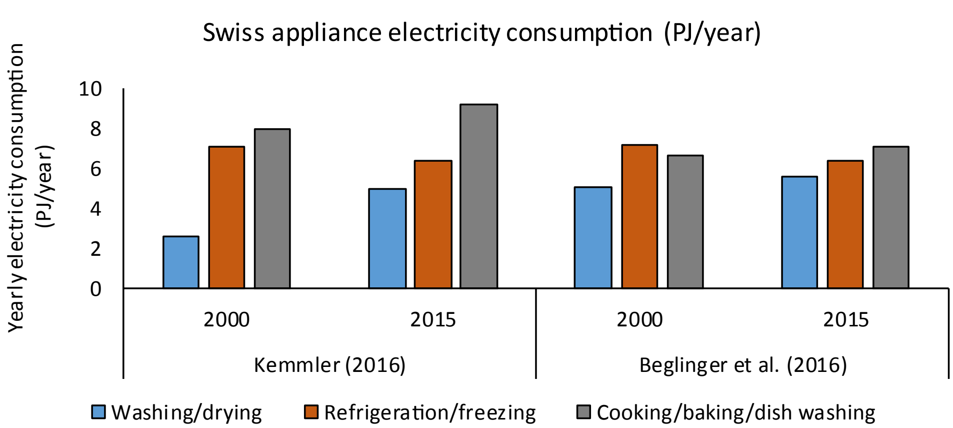


**Fig. 2.** Electricity consumptions of total stock of appliances (PJ/year).

sample size (10–250 homes) and short monitoring period (1 month to 2 years); for these reasons, they cannot be used as basis for forecasting.

**Mixed methods of surveys and monitoring:** merging national survey and monitored data of electricity consumption of appliances. A large project in Europe was REMODECE, which included monitoring of electricity loads and surveying consumer lifestyles and comfort levels in several EU member states [36]. However, their analysis is limited to trends and energy savings between 2002 and 2008. A similar study was conducted in Norway [37] and in the UK [38], where the electricity consumption of different appliance groups was estimated using national energy survey and monitored data.

Lessons for future projections of appliance stock and their consumption can also be learned from the waste management field which usually uses dynamic stock models to estimate the number of appliances, which will become obsolete in the future. These studies mostly cover consumer electronics [39,39,41] but some also study household appliances [14].

## 3. Methods

### 3.1. Overview

In this section, we present the combined stock model and electricity demand model that we developed for white goods. The stock model was constructed (in Matlab) based on the rates of sale and waste of appliances (Section 3.2). The appliance stock in use was then coupled with electricity consumption data (Section 3.3). Finally, the method to calculate the cost effectiveness of appliance replacement is presented in the Section 3.4.

### 3.2. Stock model

The stock model was constructed based on the principles of material flow analysis. As first step, the appliance stock is determined using estimated ownership levels by type of appliance in Swiss households. In our case this concerns the year of 2011 due to the availability of survey data (more detailed information and calculation in Section 3.2.1). The dynamic changes in the stock are determined by the sales of appliances (entry of appliances into the stock) and the probabilities of obsolescence, allowing to represent the number of appliances which have reached their lifetime and are hence leaving the system as waste flow (Fig. 3). For example, the domestic sales of 2011 entering the appliance stock and the obsolete appliances of 2011 leaving the stock are added to the stock by the end of 2010 to determine the stock by the end of 2011. This type of calculation is repeated for each year in the period 2000–2035. Forecasting of sales data and lifespans are explained in Section 3.2.2 and Section 3.2.3, respectively.

To implement this approach for the purpose of this study, a novel detailed model was developed by the incorporation of the sales of appliances and probabilities of obsolescence for each energy efficiency label. The model hence allows to study not only present-day market conditions but also different future pathways, thereby overcoming the limitations of REMODECE [36] and IDEA [23] mentioned in Section 2.3. Moreover, the proposed approach overcomes the lack of recent surveys on appliance ownership rate and bypasses the need of costly and time-intensive survey-based data collection.

#### 3.2.1. Calculation of the current stock: ownership level of appliances

In order to represent the full Swiss stock of a year, the ownership


**Fig. 3.** Flow diagram of the stock model.

**Table 2**
Household appliance ownership levels in Switzerland in 2011.

| Appliance | Penetration rate* |
|---|---|
| Washing machine | 62.7% |
| Tumble drier | 35.1% |
| Dishwasher | 75.6% |
| Oven | 94.5% |
| Refrigerator | 111.4% |
| Freezer | 49.9% |

* Notes: All values refer exclusively to appliances located within the dwelling while shared appliances are excluded. Freezers include both upright and chest freezers.

level of household appliances had to be considered. The sales of appliances and probabilities of obsolescence account for the dynamic changes in the stock. The appliance stock of a year for Switzerland is determined by multiplying the ownership levels and number of households present in Switzerland. For this purpose, we make use of the VSE survey which is the most reliable available source on appliance ownership level in Swiss households based on survey results of a large representative population sample conducted in 2011 [28]. It provides detailed information on appliance ownership level for different socio-economic conditions; however, the sales data (shown in Appendix B) that we use to build the model and forecast the future stock (detailed information in Section 3.2.2) were only available for entire Switzerland, with no information on the socio-demographics of the buyers of the appliances. Therefore, the stock is determined for Switzerland as a whole using one single value of appliance ownership level instead of determining the appliance ownership for different socio-economic contexts. Table 2 presents the ownership of household appliances based on the VSE survey. Appliance ownership level is calculated as the number of appliances existing in the households divided by the number of households (e.g. if total of 1337 refrigerators are owned by 1200 households, the ownership level is calculated to be 1337/1200 = 111.4%). It is important to note that only appliances owned by households are taken into account, while shared washing machines and/or driers are excluded. Based on information available from the VSE survey we made some assumptions that are explained in the following:

- VSE survey asks households “do you use tumble dryers or not”, rather than asking “do you own a tumble dryer”. For washing machines, the question asked is “do you own a washing machine?” and “do you use the shared washing-machine?”. Combining this information, we hypothesized that the households that have a privately-owned washing machine and report using a tumble dryer have their own tumble dryer in their home (i.e., we assume that the share of households using their private washing machine while drying their clothes in the shared tumble dryer is very limited)
- Regarding the cold appliances, the VSE survey reports two types of fridges, i.e., “one main door fridges” and “fridge–freezers” (two doors) as well as two types of freezers, i.e., upright and chest freezers. However, this separation is not considered in this study due to the limited categorisation of the FEA sales data (the FEA data do not differentiate between fridges only and fridge-freezers and neither between different types of freezers).

#### 3.2.2. Inflow based on sales data

Sales data are published annually by FEA [42] in form of graphs presented in Appendix B, however the corresponding label classes have only been published since 2004. The annual sales data per label class were used in order to both develop the stock model and to estimate the trends in the period from 1995 to 2035. This period was chosen because the energy label regulation was first issued after 1995 with several EU

**Table 3**
Label classes available on the Swiss market and the calculation method used for the determination of the label certificate.

| Appliance | Label categories on the market post-2004 | Calculation method (directive/regulation) |
|---|---|---|
| Cold appliances | A+ + to D; A+ + + since 2012 | 2003/66/EC [10] |
| Washing machine | A to D; A+ since 2008, A+ + and A+ + + since 2012 | 95/12/EC, after 2012 reg. 1061/2010 |
| Dishwasher | A to D; A+ to A+ + + since 2012 | 97/17/EC, after 2012 reg. 1059/2010 |
| Tumble drier | A to D; A to A+ + + since 2014; A + to A+ + + since 2018 | 95/13/EC, after 2012 reg. 392/2012 [10] |
| Oven | A to D | 2002/40/EC, after 2015 reg. 65/2014 [10] |

Council Directives [43]. Table 3 summarises the label classes available on the Swiss market and the legislation establishing the calculation method used for the determination of the label class. For some appliances, new label classes appeared on the market recently. This was either a development driven by the market itself (e.g., sales of C label refrigerators were terminated in 2008), or a consequence of a legislative change (e.g., A+ + + cold appliances were introduced in 2012).

Determination of the number of appliances by energy efficiency class in the period 2004–2015 is straightforward since the data is available for these years. For earlier years, we linearly extrapolated the trends using the sales data of 2004–2015 (12 data points) to calculate the additions to the appliance stock for each energy efficiency label. For the period after 2015, the situation is more complicated since A+ + and A+ + + categories appear not before 2012 and the number of data points (three) is insufficient for extrapolation. Based on trends of appliance sales on the Swiss marketas well as considering the strict Swiss minimum energy performance standards, we make the optimistic assumption that after 2015, all appliances sold will be at least A+ + and that after 2020, only A+ + + will be sold. This assumption was applied to all appliances except for ovens and stovetops, for which no appliance types beyond class A are present on the market.

### 3.2.3. Waste flow

The probability that an appliance will become obsolete is modelled using a Weibull distribution [44]. The Weibull function provides a distribution of obsolete (waste) appliances for a given population through time, i.e., it represents the probability that an appliance will become obsolete in the year $y_{obs}$ if it was sold in the year $y_{sold}$. Fig. 4 demonstrates the shape of the Weibull function at the example of ovens purchased in the year 1990.

Wang et al. [45] have shown that other statistical distributions such as Gauss distribution fit the lifespan of most products less well than the Weibull distribution. The Weibull lifespan distribution $L$ (see Eq. (1)) is defined by the time varying shape parameter $\alpha(y_{sold})$ and the scale parameter $\beta(y_{sold})$, also referred to as the characteristic life. Ideally, Swiss shape and scale parameters would be applied to the stock data, but no parameters could be found specifically for Switzerland. Therefore, we use empirical parameters determined for the Netherlands [45]. These values are also used in the United Nations University Guidelines on classification, reporting and indicators 2015 [46]and were therefore considered as credible.

$$L(y_{sold}, y_{obs}) = \frac{\alpha(y_{sold})}{\beta(y_{sold})^{\alpha(y_{sold})}} \cdot (y_{obs} - y_{sold})^{\alpha(y_{sold})-1} \cdot e^{-\left[\frac{y_{obsl} - y_{sold}}{\beta(y_{sold})}\right]^{\alpha(y_{sold})}} \tag{1}$$

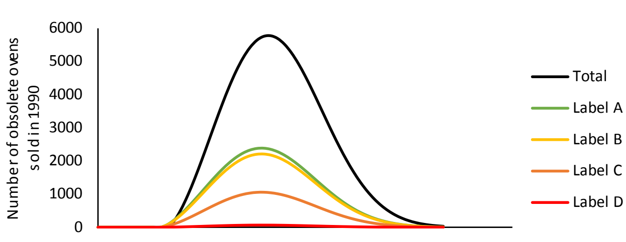


**Fig. 4.** Number of obsolete ovens per year for the devices sold in 1990.

**Table 4**
Weibull parameters and average lifespans of appliances.

| Appliance | Weibull parameters [45] | | Survey data characteristic life [47] | |
|---|---|---|---|---|
| | 2006–2008 | | 2008 | 2012 |
| | $\alpha$ | $\beta$ | $\beta'$ | |
| Dishwasher | 1.6 | 13.1 | 12.8 | 12.4 |
| Oven | 2.5 | 18.0 | 16.2 | 13.8 |
| Washing machine | 2.2 | 13.9 | 12.4 | 11.9 |
| Dryer | 2.6 | 16.5 | 13.4 | 11.9 |
| Refrigerators | 2.2 | 16.5 | 15.7 | 13.5 |
| Freezers | 2.6 | 23.2 | 19.5 | 15.5 |

In order to cross-check the validity of the Weibull scale factors ($\beta$ in Eq. (1)) from Wang et al. [45] for our purposes, we compared them with empirically obtained mean lifespans of obsolete appliances in Germany [47], as shown in Table 4 under $\beta'$. One reason for the difference between the distributions of $\beta$ and $\beta'$ is that the mean achieved lifespan assumes a symmetric normal distribution, while the Weibull distribution is characterised by a longer tail end which also explains the slightly higher average lifespan as noted by Prakash et al [47].

## 3.3. Electricity demand model

In order to calculate the electricity consumption for each appliance category, the label class was converted into electricity consumption data using the corresponding calculation method (Table 5). Due to unavailability of monitored data, we use the standard consumption which is defined by the authorities in accordance with Annex VII of the European Commission [48] and depends on the capacity/volume, number of annual cycles, and sometimes other factors such as time of a program. This enables a comparison of different types of appliances on the market. For ovens and cold appliances, only one method was in place in years 2004–2015. For other appliances, the first method was in place until roughly 2010 when the European Commission updated the label regulations, and therefore this method is applied to all appliances sold prior to 2010 [49]. Earlier energy labels (prior to 2010) were based on the consumption of the appliance of a standard cycle (in kWh per cycle), making the conversion from label class into annual electricity consumption straightforward. However, post 2010, the regulations prescribe a different approach based on the energy efficiency index (EEI). The EEI is a result of annual energy consumption of a given appliance divided by the standard annual consumption of the respective device. When converting the label information into consumption, the 'minimal effort' assumption is made. For example, for a class A+ + + dishwasher, which is characterised by an EEI ≤ 50, we choose an EEI value of 50 for calculating the consumption. This simplifying assumption hence using mean values for electricity consumption is considered to provide a sufficiently accurate approximation of the demand. The same approach was implemented by Topten when calculating the average efficiency of appliances sold in a given year [50] and by the IDEA when calculating appliance electricity consumption [23]. Uncertainty related to occupant behaviour (such as the amount of clothes charged per washing cycle and programme choice) was ignored as such

**Table 5**
Variables used to calculate the annual consumption for different label categories of appliances (the highlighted consumption was applied in the model).

| Annual consumption in kWh per appliance | Number of annual cycles | Number of annual cycles (reference regulation) | Assumed maximum capacity | Calculation methods between the years 2004 and 2015 | Electricity consumption (in kWh per year and appliance) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | A+++ | A++ | A+ | A | B | C | D |
| Washing machine | 194 | 220 (1061/2010) | 8 kg capacity | 95/12/EC | | | | 295 | 357 | 419 | 481 |
| | | | | 1061/2010 | 174 | 196 | 223 | 257 | 291 | 329 | 366 |
| Tumble drier | 103 | 160 (392/2012) | 8 kg capacity | 95/13/EC | | | | 453 | 527 | 602 | 676 |
| | | | | 392/2012 | 114 | 151 | 199 | 308 | 360 | 402 | 450 |
| Dishwasher | 215 | 280 (1059/2010) | 13 place settings | 97/17/EC | | | | 230 | 274 | 317 | 360 |
| | | | | 1059/2010 | 180 | 202 | 227 | 256 | 288 | 324 | 360 |
| Oven | 99 | 120 (2002/40/EC) | 64 litre volume | 2002/40/EC | | | | 86 | 107 | 128 | 137 |
| Refrigerator | n/a | n/a | 281 litre volume | 2003/66/EC | 126 | 189 | 251 | 314 | 429 | 543 | 628 |
| Freezer | n/a | n/a | 213 litre volume | 2003/66/EC | 135 | 202 | 269 | 337 | 459 | 581 | 673 |

information was not available. The energy label calculation method (including electricity consumption) considers the number of annual cycles representing a typical user behaviour (calculated using data from the VSE household survey). Table 5 illustrates the number of cycles calculated using the VSE survey. In the present study, assumptions about standard capacities of appliances were made based on data of appliances available on the market [51]. Appliances labelled A+ and higher were only sold after the introduction of the new calculation method. On the other hand, appliances labelled A, B, C and D were all sold before the method had been updated.

### 3.4. Cost effectiveness of appliance replacement

To evaluate the cost effectiveness, the annualized cost of appliance replacement is divided by the annual energy savings (PJ/year). The cost and energy savings are established as difference between the chosen efficient equipment and the standard device, with the latter representing the standard choice[1] in the case of failure replacement (based on the Swiss legal minimum standard in 2016, this is label A+ for dishwashers, tumble dryers and washing machines; label A++ for freezers and refrigerators; and A for cooking appliances). The consumption in each label class is determined based on Table 5.

Replacement refers to the situation that households replace their appliance with a more efficient one when it breaks down or reaches maximum lifetime. Early replacement for reasons of energy efficiency improvement is not considered (see below Section 4.3). The specific cost of energy efficiency improvement (also referred to as levelized cost of saved energy) is calculated by equation (2) presented in Heidari et al. [24].

$$\text{Specific cost}\left[\frac{\text{CHF}}{\text{PJ saved}}\right] = \frac{a * I - B}{\Delta E_{saved}}\left[\frac{\text{CHF/year}}{\text{PJ/year}}\right] \tag{2}$$

where:

a = Capital recovery factor
I = Investment costs of the replacement in Swiss francs (CHF) (mean market price of all available appliances was calculated based on compareco.ch)
B = Annual electricity costs savings in CHF, based on an electricity price of 0.23 CHF/kWh (inc. VAT) [16]
$\Delta E_{saved}$ = Energy savings in PJ

Based on the discount rate and the lifetime of the appliance, the capital recovery factor is calculated using the following equation:

$$a = \frac{r}{1-(1+r)^{-L}} \tag{3}$$

where:

r = Discount rate
L = Average lifetime of appliance based on Table 4

Prices of appliances in Switzerland (in CHF) are presented in Table 10 in Appendix C. In line with the reasoning presented by Heidari et al. [24], we choose a medium discount rate of 15% for households, considering the suggestions by Energy Efficiency Directive (European [52], Steinbach and Staniaszek [53], and Blok and Nieuwlaar [54].[2] The chosen value falls into the range for decisions made in companies. The residual economic value of the broken appliances is neglected because there is no formal secondary market for such appliances.

### 3.5. Model download

An example implementation of the model, in the form of a Matlab code, has been made available for free download [55]. It contains algorithms of the life-span distribution for appliances, forecasting of the stock and the corresponding electricity demand. The source code is open and may be readily adapted for specific application, with due acknowledgment to the authors.

## 4. Results

### 4.1. Stocks of household appliances

Fig. 5 presents the results of our stock model between 2000 and 2035 alongside literature values published by Beglinger et al. [29], IEA [13], and Prognos' 2050 projections [16] to verify the developed model. The stock is presented with a breakdown of energy efficiency labels, however, only overall stock data can be compared due to lack of more detailed information in the quoted reports. The IEA [13] only covers the years of 2000–2009; Beglinger et al. [29] cover the years of 2000–2015, which coincides with the temporal scope of our study. For future years (between 2015 and 2035), Prognos 2050 only provides results for 2020, 2030, and 2035. Our results for the stocks of freezers and refrigerators in the period 2000–2015 were found to be close to the

[1] The notion of "standard" used here (in the sense of a typical product or a reference product on the market) differs from "standard" in the previous section which refers to the harmonised way of measuring energy use and establishing EEI classes by the authorities.

[2] We assume here that all costs are borne by the household (referred to as "DIY approach" by [29] in the case of lighting). For lighting and other small devices, an alternative approach is occasionally implemented where the utility bears both the purchase costs and the installation costs (referred to as "utility program" by [29]. This type of approach is not realistic for white goods given the much higher purchase costs compared to light bulbs.

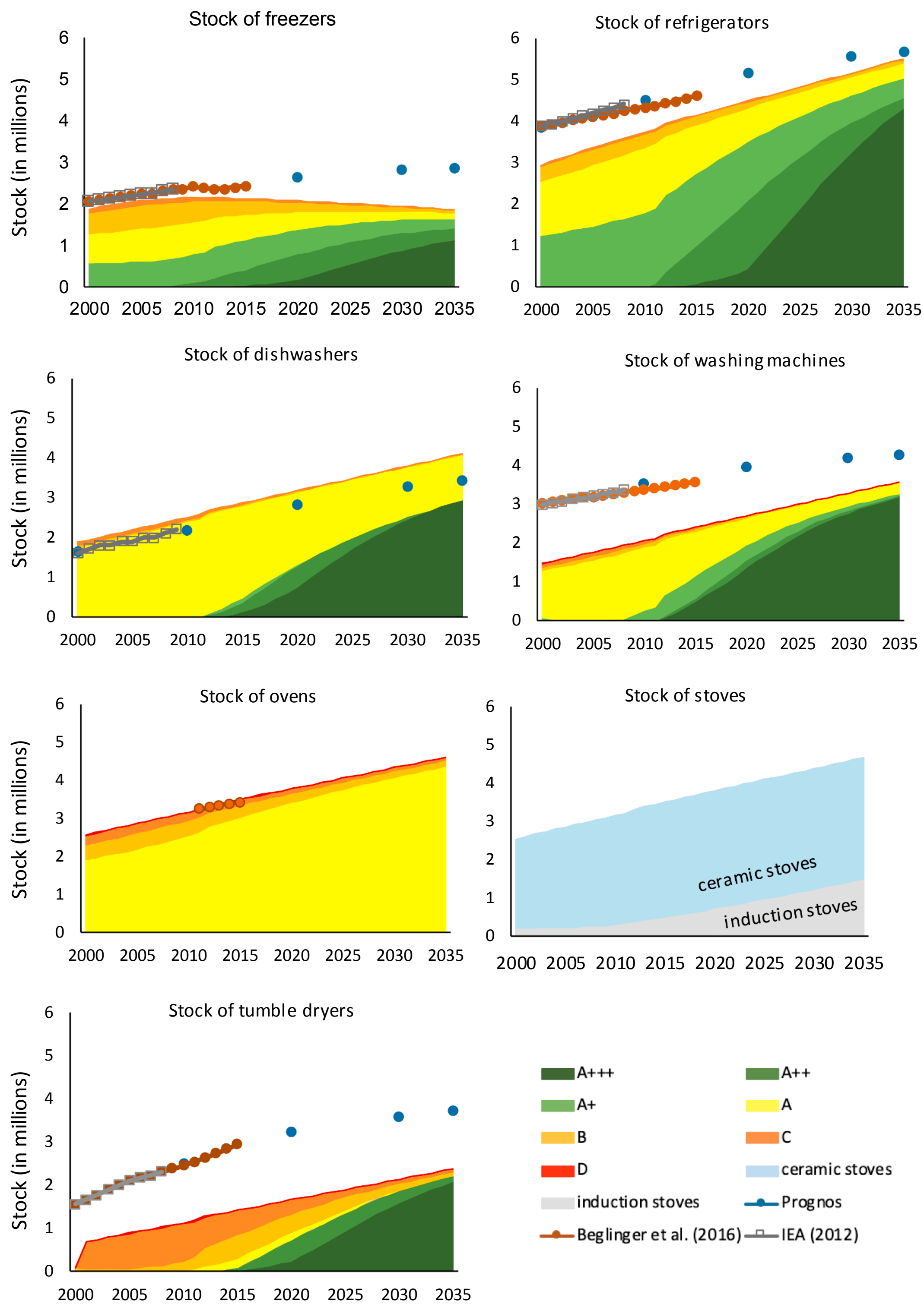


**Fig. 5.** Projected stocks of investigated household appliances in Switzerland – Model results and comparison with Beglinger et al. [29], IEA [13] and Prognos 2050 [16].

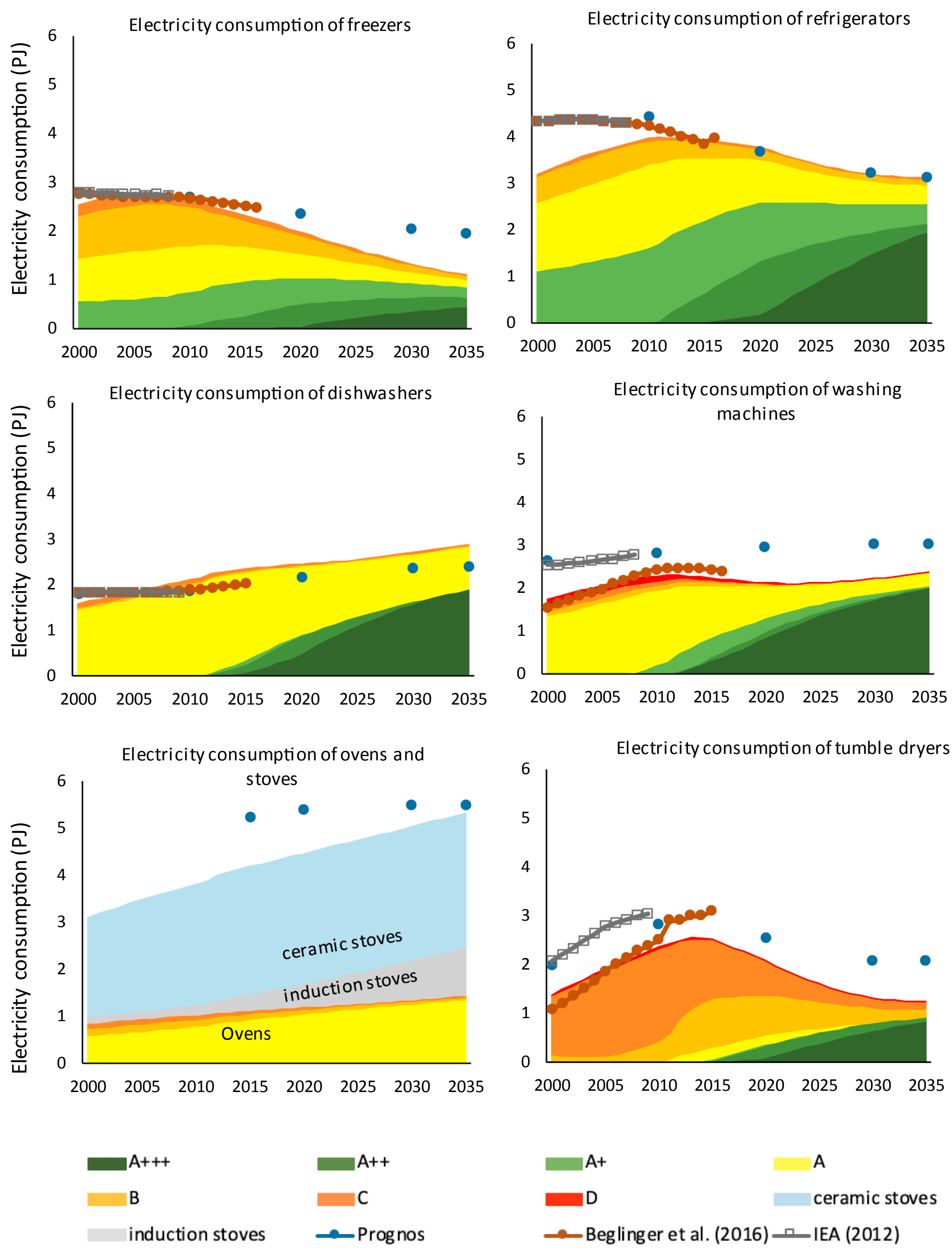


**Fig. 6.** Projected electricity demand of household appliances in Switzerland – Model results and comparison with Beglinger et al. [29], IEA [13] and BAU projections according to Prognos 2050 [16].

results of Beglinger et al. [29], albeit on the low side for refrigerators. Our estimates of the stock of tumble driers and washing machines are clearly lower than those of Beglinger et al. [29] and the IEA [13]. Beglinger et al. [29] explicitly states that shared washing machines and tumble driers are included in the service sector rather than in the household sector, which is in line with our approach[3]. The values presented by Beglinger et al. [29] imply an equipment rate[4] for washing machines of 81% and for tumble dryers of 61%, while our assumed appliance rates based on the VSE survey (2011) are 62% and 39% for washing machines and tumble dryers, respectively (explaining the different trajectories in Fig. 5). In the case of freezers, the distribution of

[3] In Switzerland, it is customary for apartment buildings to have shared washing machines and tumble driers in the basement. The related electricity use is assigned to the service sector instead of the households and this electricity use is therefore also outside the scope of this paper.

[4] Number of households with equipped with a given device divided by total number of households.

label categories within the stock is currently very heterogeneous and contains appliances ranging from A++ to B in rather similar proportions. A similar distribution (but with a lower share of the A++ appliances) is observed for refrigerators and driers, where the current stock spans from C-labelled appliances to A+++ appliances. Stocks of dishwashers and washing machines are currently dominated by label A up to label A+++ appliances. Stocks of ovens and stovetops are even more homogenous, with currently only two or three appliance types in the stock.

As time passes, the composition of stock changes gradually due to the relatively long lifespan of appliances, especially for ovens/stoves, cold appliances, and tumble driers. For almost all appliances, A+++ labels achieve a dramatic increase partly due to our model assumption, according to which only A+++ appliances will be sold after 2020. If this assumption were not to materialize, the share of A+++ appliances would be replaced by a proportion of A+ and A++ appliances. We assumed the most optimistic scenario in order to understand which savings can be achieved in the best case and also because the limited history of sales data made it impossible to consider more specific circumstances.

The comparison of our projected values with PROGNOS 2050 [16] shows larger discrepancies than the comparison of our ex-post modelling results with Beglinger et al. (see above). The strong growth in the appliance stock according to Prognos can to some extent be attributed to a growth in the number of households. However, based on past trends we project some stocks (dishwashers, refrigerators) to increase by as much as 40% between 2015 and 2035 (hence indicating a clearly increased equipment rate), whereas the growth in the number of households (Table 1) in these years is about 20%.

### 4.2. Electricity demand of household appliances

By analogy to the discussion on appliance stocks, Fig. 6 presents our results for electricity demand between 2000 and 2035 alongside literature values published by Beglinger et al. [29], IEA [13], and Prognos 2050 projections [16] for verification. For the past, the results of yearly electricity consumption of refrigerators and dishwashers were found to be close to the results of Beglinger et al. [29] and IEA [13]. For freezers, the discrepancy in electricity use is primarily related to the lower projected future stock according to our model. Although the stock of washing machines and tumble driers is lower according to our model (see Fig. 5; due to different assumptions regarding the equipment rate), the results of yearly electricity consumption were found to be relatively close to the results of Beglinger et al. [29] and IEA [13]. The electricity consumption of stoves is somewhat lower compared to Beglinger et al. [29].

Fig. 6 also displays our model results for the future based on the trends evident from the 2004 to 2015 scenario (i.e., reference scenario [REF], see below). While the stocks of most appliances continue to grow over the years (see above Fig. 5), their electricity demand ranges from a slight growth (ovens, stovetops, and dishwashers) to a significant decrease for some appliances (freezers, refrigerators, and driers). For all appliances (except for ovens and stovetops) the energy performance of the stock improves, but this trend is not always sufficient to compensate for the growth of the appliance stock. For example, for washing machines, the consumption first slightly drops due to an improved structure, but this effect is later compensated by the growing stock, causing a modest increase in consumption after the year 2025. Moreover, the stock model projects that the stock of freezers will slightly decrease because the sales of freezers have been decreasing since 2011 [42]. There are large differences in energy consumption of ovens and stovetops in this analysis compared to PROGNOS 2050 [16].

### 4.3. Comparison of scenarios for energy efficiency labelling

This section compares two scenarios for energy efficiency labelling which are the REF scenario and the so–called 'maximum efficiency' (MAX EFF) scenario. REF scenario (presented in Fig. 6) is based on the current set of policy measures which include mandatory minimum energy performance standards (MEPS) and appliance labelling. On the other hand, the MAX EFF scenario considers the emergence of the novel technologies. The aim is therefore to first show whether the current policy measures are effective for achieving energy saving targets and secondly to show the possible contribution of novel technologies by comparing the two scenarios. The MAX EFF differs from the REF scenario by the substitution of all A+++ appliances by even more efficient appliances from 2020 onwards. Table 6 presents the efficiencies assumed for the best appliances in the MAX EFF scenario (based on estimates by few energy experts in Switzerland) relative to the current A+++ appliances on the market. For example, 60% means that the new refrigerators entering market after 2020 will consume only 60% of the electricity required by A+++ refrigerators in 2015. It has been estimated that the new super-efficient appliances will be sold at the same price as today's premium products (A+++) and that the current premium products will be 10% cheaper than today. The MAX EFF scenario was applied to all investigated appliances, except for ovens and stovetops. For stovetops and ovens, no innovation is foreseeable.

Fig. 7 shows the evolution of energy use between 2020 and 2035 according to the two scenarios and Table 7 presents the decrease in electricity consumption in the MAX EFF scenario relative to the REF scenario in 2035. The difference in energy use between the two scenarios is most pronounced for those appliances for which (i) a stronger improvement in energy efficiency is expected (e.g., washing machines and dishwashers; Table 6) and (ii) a higher share of the stock is renewed (e.g., the decrease is lower for dishwashers, as the percentage of A+++ in the stock of 2035 is 70%, whereas it is 90% for washing machines).

Table 8 summarises the changes in electricity demand between 2015 and 2035 as calculated by our model (both REF and MAX EFF scenarios) and according to two scenarios presented by the Prognos report (Busines as usual [BAU] and Policy Measures [PM]) [17]. Both studies project a decrease in electricity consumption between 2015 and 2035 for freezers, refrigerators, and tumble driers; an increase in the electricity demand of dishwashers is foreseen for 2035 compared to 2015 both according to our REF scenario and Prognos' BAU scenario. However, electricity demand could be further lowered for nearly all appliances if more energy efficient technologies were implemented (i.e., a decrease by 18% in our scenario "MAX EFF" and by 10% in Prognos' PM scenario). For washing machines, our model anticipates 8% more electricity demand in 2035 compared to 2015 for the REF scenario, as opposed to Prognos projecting a decrease of 3% for the BAU scenario. In our MAX EFF scenario, the electricity demand of washing machines decreases by 37% until 2035, while the respective value projected by Prognos is 16%. Overall, our projected electricity savings until 2035 are 25% for the MAX EFF and 8% for the REF scenario. When making these comparisons it should, however, be kept in mind that the MAX EFF scenario is based on the very optimistic scenario of immediate diffusion of very highly efficient appliances, which are not yet on the market and are assumed to replace all A+++ appliances. Even our energy projections for the REF scenario are rather optimistic because we assume that all appliances sold after 2015 and 2020 will be at least A++ and A+++ respectively (see above, Section 3.2.1).

Fig. 8 shows changes in the composition of electricity demand by appliances between 2015 and 2035. While cold appliances nowadays represent approximately one third (36%) of total consumption (which corresponds well to the data described in Fig. 1), their share is expected to decrease to approximately one quarter by the year 2035 for REF and EFF scenarios. In the MAX EFF scenario, the share of washing/drying appliances is expected to marginally decrease (from 26% to 23%). The combined share for stoves, ovens, and dishwashers is anticipated to grow from 36% to 51%, with each of these appliances increasing its share. In the EFF scenario, in 2035 this share is even higher (55%), as

**Table 6**
Energy efficiency improvement of appliances according to expert estimates in Switzerland.

| | Best energy efficiency label in 2015 | Energy consumption of best appliance energy efficiency in 2020–2025 compared to 2015 | New technology assumed for best appliances as of 2020 |
|---|---|---|---|
| | [62] | (Estimated by energy experts in Switzerland) | |
| Freezer | A+++ | 80% | Second thermodynamic cycles for freezer |
| Refrigerators | A+++ | 60% | |
| Tumble dryer | A+++ | 80% | Heat exchange, heat pump and/or heat storage |
| Dishwasher | A+++ | 50% | |
| Washing machine | A+++ | 50% | |

the rest of the appliances will undergo further decrease.

### 4.4. Cost effectiveness of appliance replacement

Table 9 presents the replacement steps assumed when estimating the cost effectiveness. The costs and energy savings are presented in two steps for each appliance: in the first step, the least efficient appliances (present in the stock in 2016) are replaced with the most efficient ones, followed by moderately inefficient appliances replaced with the most efficient ones in a second step. For example, in replacement step of Freezer I, 357,000 of B, C, and D-labelled freezers are replaced with A+++ appliances; and 555,000 A-labelled freezers are likewise replaced with A+++ appliances. With this approach we estimate the "potential" energy savings if all the current appliances leave the stock today and are replaced by new technology. In addition, we also analysed the replacement of inefficient and of moderately inefficient appliances by the new technologies presented in Table 6. As explained in Section 3.4, both the cost and energy savings are established as difference between the chosen efficient equipment and the standard appliance (see third column from the right in Table 9).

Fig. 9 shows the cost effectiveness of the replacement of the white goods for failure replacement and maximum lifetime replacement from the household perspective explained in Section 3.4. Each step represents the measure presented in Table 9. The height of the measure shows the specific cost (CHF/GJ) and the width of the step shows the total electricity saving potential from the measure in Switzerland. In general, the specific cost of energy efficiency improvement (i.e., levelized cost) are found to be high. The only cost-effective option is to replace B/C and D-labelled freezers by A+++ labels. The replacement of ovens is the least cost-effective option (1170 CHF/GJ in the REF scenario). This is partly due to the fact that white goods are quite expensive in Switzerland, while household electricity prices are within the European range [63]. Interestingly, appliances with relatively low specific costs such as freezers – and to some extent refrigerators – are also the ones to experience a reduction in energy consumption by 2035 (Fig. 6). Conversely, appliances with high specific costs for energy

**Table 7**
Percentage decrease in electricity demand by "MAX EFF" scenario in comparison with the "REF" scenario in 2035.

| Appliances | % difference between "REF" and "MAX EFF" scenario electricity demand in 2035 (PJ annually) |
|---|---|
| Freezer | −9% |
| Refrigerators | −25% |
| Tumble drier | −14% |
| Dishwasher | −33% |
| Washing machine | −42% |

savings are expected to either stagnate in terms of electricity consumption (washing machines) or to increase. Intermediate specific costs are found for tumble driers, the specific costs take an intermediate position. As mentioned above, only failure replacement and maximum lifetime replacement are studied in this paper. We do not consider early replacement because its costs would be even higher than for failure replacement. When the replacement of the white goods with new technology ("MAX EFF" scenario in Table 6) is considered, the replacement is relatively more cost-effective due to increase in energy efficiency. For example, for the case of "Refrigerator II", the specific cost decreases from 157 CHF/GJ to 94 CHF/GJ.

It should be noted that the chosen approach applies the immediate replacement of the current stock based on today's standard appliances (Table 9). In contrast, replacement of a part of the stock at a later point in time implies that the standard appliance will be more energy efficient resulting in a clearly smaller cost differential, while energy savings remain significant. At that point, cost effectiveness improves. For example, when label A++ is assumed to be the standard device for dishwashers instead of label A+, the specific cost and payback period decreases from 455 CHF/GJ to 299 CHF/GJ and from 44.5 years to 31.2 years for the case of "Dishwasher I", respectively.

Fig. 10 shows the payback time of energy efficiency improvement of the stock of white goods. The payback time for replacement of the white goods are generally quite long. For the replacement of freezers of labels

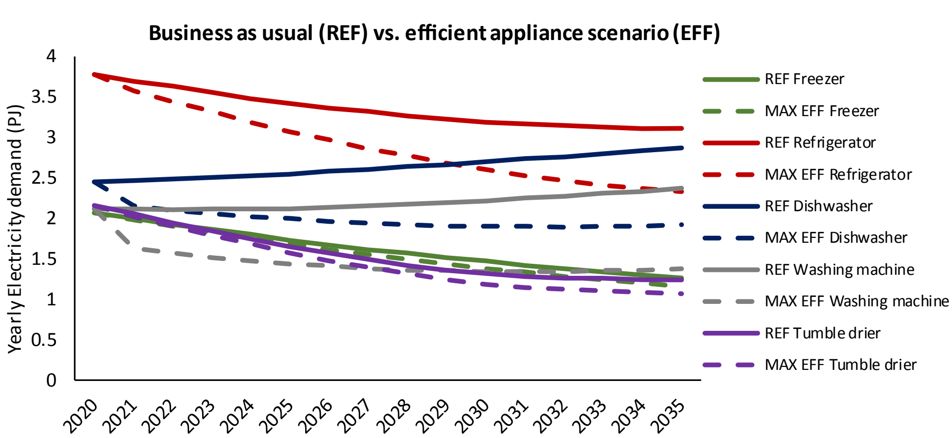


**Fig. 7.** Future consumptions of various appliance types under the two distinct scenarios.

**Table 8**
Percentage changes in appliance stock and electricity demand as projected by the model in this study and PROGNOS 2050 report.

| Appliance | Electricity demand REF 2035 vs. 2015 | Electricity demand EFF 2035 vs. 2015 | PROGNOS BAU consumption 2035 vs. 2015 | PROGNOS PM consumption 2035 vs. 2015 |
|---|---|---|---|---|
| Freezer | −47% | −51% | −12% | −12% |
| Refrigerator | −21% | −40% | −23% | −44% |
| Tumble drier | −51% | −58% | −23% | −41% |
| Dishwasher | 22% | −18% | 16% | −1% |
| Washing machine | 8% | −37% | −3% | −16% |
| Oven | 28% | – | 5% | 27% |
| Stovetop | 27% | – | | |
| Total | −8% | −25% | −5% | −10% |

of A/B/C with A+++ devices, we find the shortest payback period, which averages to 5.5 years. At the other extreme, ovens have the highest payback time, which is 110 years. When the replacement of the white goods with very highly efficient devices ("MAX EFF" scenario in Table 6) is considered, the payback periods of washing machines and dishwashers decrease to almost half. Nevertheless, most options remain economically unfeasible. However, by analogy with the explanation above, cost effectiveness improves for replacement of part of the stock at a later point in time.

## 5. Discussion

From a research perspective, this study has contributed to an improved understanding of how to model the appliance stock and electricity consumption of household appliances in Swiss homes. The chosen approach is based on historical sales data and lifespans to project the current and future appliance stock when actual data for equipment rates for several years are not available. The analysis is, however, constrained by the limited data availability in Switzerland. For example, our study is based on the standard usage of appliances, although electricity consumption can vary significantly among households depending on factors such as the amount of clothes charged per washing cycle, programme choice and so on. It would clearly improve the quality of the model results to use data on the actual use of appliances rather than adopting standard values. If reliable data of this type was available, the related uncertainty could be quantified. In absence of such data, the usage of mean values for electricity consumption depending on EEI enables a reasonable reconstruction and projection of the total yearly electricity demand of appliances. Further research involving appliance monitoring is recommended to capture the impact of behaviour. Furthermore, more historical sales data (before 2004) would allow improving the model, since an increased number of data points would reduce the uncertainty.

The results of this study should be of key interest to government policy makers and utilities interested in understanding the drivers of electricity demand in Switzerland and energy efficiency improvement. Two main avenues for energy demand reduction exist. The first avenue is the reduction of the stock size, which is expected only for freezers, in view of the decreasing sales since 2004 (Fig. 11). For all other white goods, this paper indicated a rising stock due to the growing number of households and increasing ownership. The second avenue is the transition to more energy efficient appliances that will help to decrease the electricity demand in the future or at least limit its growth. The latter case is found, for example, for dishwashers and washing machines in the REF scenario: although the future stock consists of more energy efficient appliances compared to 2015 (70% and 90% of A+++ appliances compared to 4% and 20% in 2035 for dishwashers and washing machines, respectively) the electricity consumption does not decrease as the number of dishwashers and washing machines in homes increases. This is because of population growth and because people own more private washing machines rather than using the ones in the apartment's communal place [28]. Some additional energy could be saved by more energy efficient behaviour amongst occupants, i.e. more considerate use of appliances (e.g., programme choices, frequency of usage, etc.). Thanks to the low growth of cold appliances in combination with a growing percentage of energy efficient appliances in the stock, their electricity demand is decreasing over time. In view of unexploited technical opportunities for further energy efficiency improvement (beyond A+++) the minimum energy performance standards could be further tightened allowing the technology frontier to move ahead (e.g., as shown in "MAX EFF" scenario in Table 8). Future Swiss electricity may well be based on more fossil fuels (e.g. CHP and natural gas combined cycles) than today (Prognos, 2012), in which case energy demand reduction through energy efficiency standards and labelling could directly contribute to Switzerland's climate policy targets.

This paper furthermore investigated the cost effectiveness of failure replacement for several appliances. The results show that today only the replacement of freezers is nearly or actually cost-effective. If new,

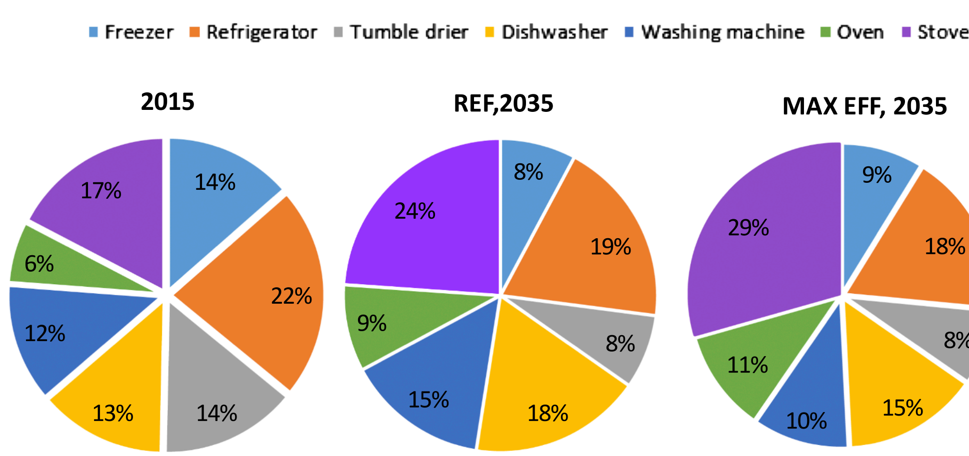


**Fig. 8.** Shares of electricity consumption by each appliance type in years 2015 and 2035 in REF and MAX EFF scenario.

**Table 9**
Replacement steps in the estimation of cost effectiveness.

| Appliance and replacement step | Label class of replaced appliances | Number of appliances replaced (in thousands) | Standard appliance | Most efficient appliance today | Maximum efficiency in future |
|---|---|---|---|---|---|
| Freezer I | B/C/D | 357 | A+ + | A+ + + | 0.8 · A+ + + |
| Freezer II | A | 555 | | | |
| Refrigerator I | A/B/C | 1317 | A+ + | A+ + + | 0.6 · A+ + + |
| Refrigerator II | A+ | 1678 | | | |
| Tumble Drier I | C/D | 510 | A+ | A+ + + | 0.8 · A+ + + |
| Tumble Drier II | A/B | 732 | | | |
| Washing machine I | B/C/D | 86 | A+ | A+ + + | 0.5 · A+ + + |
| Washing machine II | A | 1049 | | | |
| Dishwasher I | B/C | 50 | A+ | A+ + + | no innovation |
| Dishwasher II | A | 2212 | | | |
| Oven I | C/D | 449 | A | A+ | no innovation |
| Oven II | B/A | 3111 | | | |

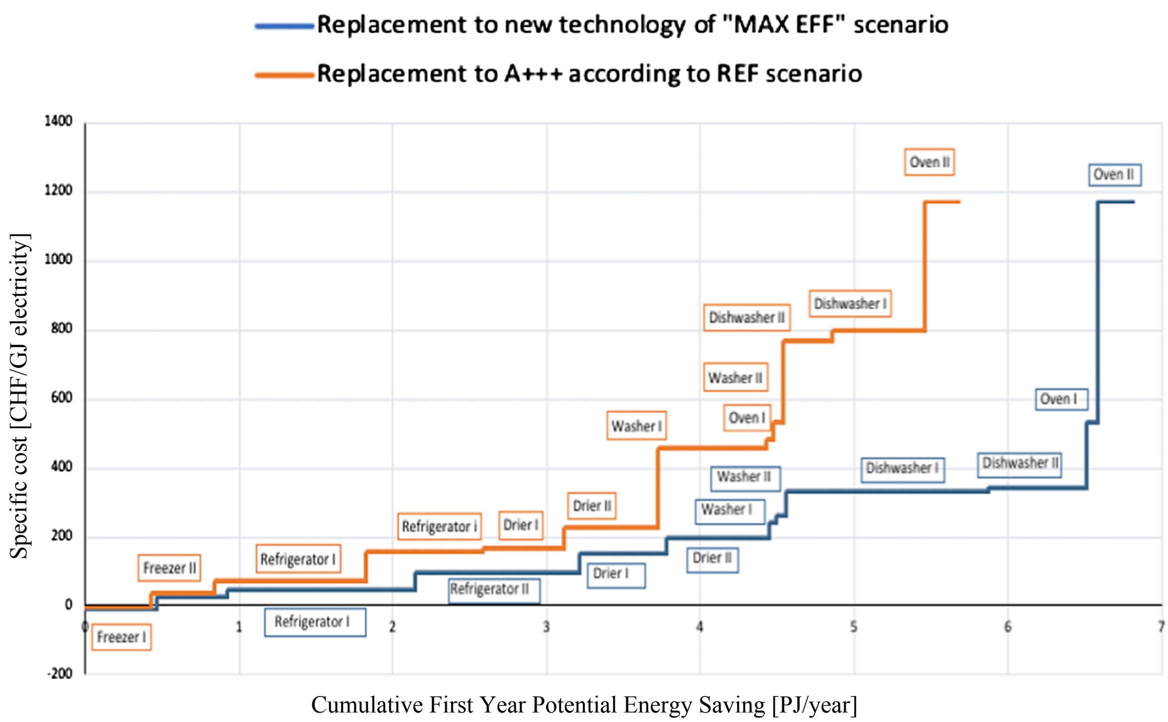


**Fig. 9.** Cost effectiveness of appliance replacement (VAT are not included) for “REF” and “MAX EFF” scenario.

very highly efficient appliances can be successfully commercialised, this would allow to significantly decrease the costs per unit of energy saved (see Fig. 9). Similarly, under the assumption of a more energy efficient standard device, the replacement of a part of the stock with very highly efficient appliances at a later point in time improves cost effectiveness. However, both cases do not automatically make the replacement cost-effective. The limited or even unfavourable cost effectiveness for most other appliances is partly caused by the high price of energy-efficient appliances (compared to standard device) as well as relatively low electricity prices in Switzerland. This also explains why payback periods are generally long. It indicates that cost effectiveness would not be the primary motivation for customers, suggesting that policy makers should target both technical measures and social interventions (behaviour change). For example, in a recent survey that assessed motivations to adopt electricity tariffs aiming at the reduction of household energy use, about 48% of participants reported that they would be motivated to reduce their energy consumption for environmental reasons, while 41% reported that they would mainly be motivated for financial reasons [56]. Policy makers thus might envisage a combination of interventions aiming at these different motivations to promote adoption of more efficient devices. For example, re-designed energy labels may emphasise more strongly both the financial and the environmental consequences of reductions in energy use.

## 6. Conclusion

In this study, we studied the development of the stock of cold appliances (refrigerators, freezers), wet appliances (dishwashers, washing machines, tumble driers), and cooking appliances (ovens, stovetops) as well as their energy use and costs for energy efficiency improvements with respect to these appliances in Switzerland. The model was developed and applied using data on appliance rates, sales, and lifetime distribution. We compared two scenarios (Reference scenario [REF] and Maximum efficiency scenario [MAX EFF]) to those of the Prognos study (2012), which served as basis for the development of the Swiss Energy Strategy 2050. Finally, the cost effectiveness of switching to more energy efficient labels was determined. This research shows that the stock of appliances is expected to increase in the future, except for freezers. Therefore, stock renewal and expansion are opportunities to increase the share of highly efficient appliances (e.g., A+ + + labels) at the expense of lower-efficiency appliances (e.g., A, B and C- labels). Although the future stock will consist of clearly more energy efficient

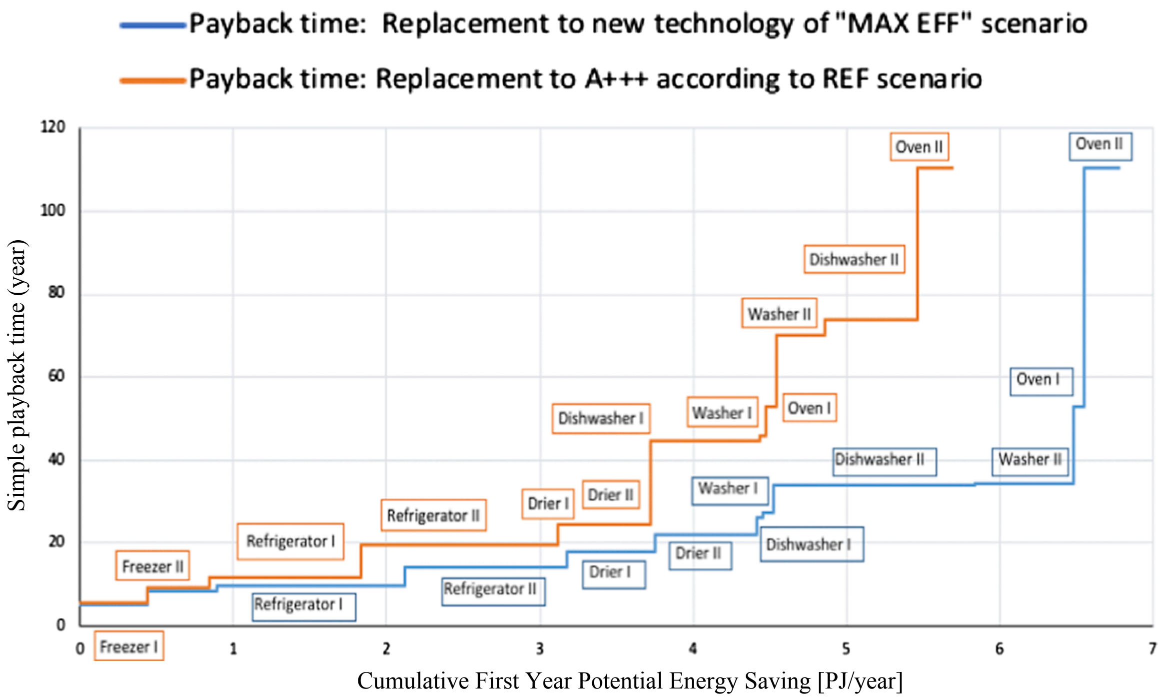


**Fig. 10.** White goods replacement payback time vs. energy saving potential in 2016 for “REF” and “MAX EFF” scenario.

appliances, the electricity consumption does not necessarily decrease for every appliance type due to the limited rate of further efficiency improvement and the increased number of appliances in use. Overall, we project a decrease of electricity demand of white goods by 8% by the year 2035 in the REF scenario. According to the “MAX EFF scenario” a reduction of electricity demand by 25% seems feasible until 2035. These results point to the potential contribution of energy efficiency standards and labelling for electricity demand reduction of appliances and hence also for $CO_2$ abatement, especially for countries which heavily depend on fossil fuels for electricity generation. The results for cost effectiveness of appliance replacement show that switching to more energy efficient white goods incurs high specific costs and long payback times. This is the case according to both REF and MAX EFF scenario; however, a marked decrease is found for the MAX EFF compared to REF scenario. In order to leverage the energy efficiency potential related to white goods, suitable policy measures such as new minimum energy performance standards would need to be enacted and related R&D should be encouraged. While these conclusions are based on analyses for Switzerland similar findings can be expected for other countries with comparable legislation (e.g. EU member states). Yet, further country-specific analyses are recommended.

## Acknowledgements

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## Appendix A

*Consumption of household appliances in Switzerland – a description of existing literature*

The data available on their consumption originate from surveys, monitoring of selected households or are modelled based on standard consumptions and assumption about the penetration rates of appliances. Unfortunately, in some sources, the methodology of the presented data is not explained thoroughly, thereby, hindering the comparison with data from other reports. Several major original data sources exist in Switzerland (e.g., [57,17,29,58], one was found on an international level [59] and one on a regional level in the canton of Geneva [60].

The first source is a bottom-up study by Nipkow and Gasser [61] and Nipkow [57], relying on household surveys of 1000 + households carried out by the Association of Swiss Electricity Companies (German abbreviation VSE). The 2013 study defines the consumption of appliances with the help of ‘typical’ appliance age (approximately 6 years), typical consumption per label class (manufacturer declarations), and data on the sales of appliances. The consumptions are then presented separately for single and multi-family housing and separately for a 2- and 4-person household. Moreover, the VSE survey provided data on the penetration rate and use practices in each group of households (single/multi family, number of people). Kemmler et al.’s [17] analysis of the changes in energy consumption through top-down energy system models are corrected ex-post with the development of its most important determinant factors, such as population, number of households, household size etc. For household electricity consumption this means that the model is adjusted to the sales, efficiency improvements, and real uses of appliances. Beglinger et al. [29] study is an evaluation of efficiency improvements based on the sales data. The authors remark at the beginning of the report that, according to the newly available statistics, the household size increased from 2.15 to 2.25 people, which reduces the assumption about the number of households by about 5% (assuming an unchanged population). This is said to affect the stocks of appliances too. Another reported difference between this and previous studies are said to be changes in household structure, influencing the real usage of appliances. Besides the FEA data, the authors claim to have used data on existing stocks of appliances, although it is unclear what the source is.

As opposed to the previous three sources, which are all in some way based on the sales data from the Swiss Association of the Domestic Electrical Appliances Industry (FEA), the primary source in the Gasser and Heldstab report from 2005 is the Energybox online tool. In this tool users calculate the electricity consumption of their house by selecting the types of appliances present in their home and their utilization patterns. Their selections can later be used as a data source and analysed. The advantage of this study is that the source is alternative, however, it is afflicted by a considerable amount of bias. Many users might not take the online forms seriously and can simply be 'playing' with different scenarios. The other disadvantage is that the source is slightly outdated. The international source (IEA, 2011–2014), which dealt specifically with Switzerland was the so called 'Mapping and benchmarking' project undertaken by IEA as an inter-country collaborative project designed to help policymakers understand product performance and energy consumption. The data have been supplied by each country, but the sources were unfortunately not specified in the available reports. Last but not least, the Le Strat [60] study was commissioned by the main utility provider of Geneva in order to carry out an analysis electricity demand in the canton. It included energy audits and is therefore another independent source, unfortunately it might not be representative for the whole Switzerland and is, like the report by Gasser and Heldstab [58], slightly outdated.

## Appendix B

The annual sales balance was determined based on the shares of each label class sold in a given year instead of directly taking the absolute number of appliances with a certain label, which sometimes increases drastically within a single year. The calculated annual sales shares are multiplied with the total absolute number of items sold for each household.

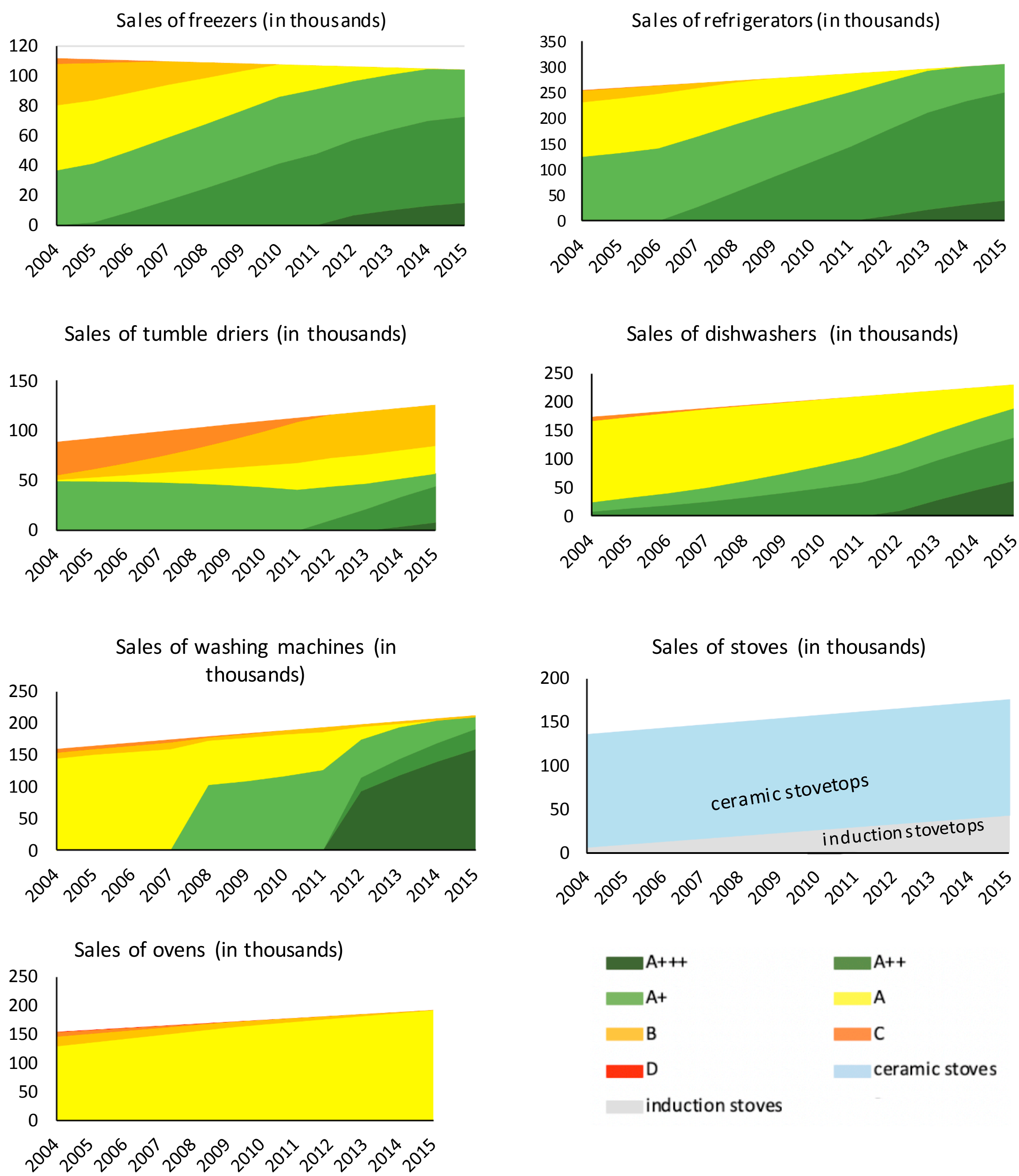


**Fig. 11.** Sales of appliance in a given year including the proportions of each label category.

## Appendix C

Table 10 presents the prices of appliances that are sold in Switzerland. The prices are calculated by taking average of price listed that are being sold in Switzerland such V-Zug, Bosch, Siemens etc. The experts in Switzerland estimated that the new energy efficient appliance would be at the same price as premiums are today.

**Table 10**
Prices of appliances in Switzerland in francs.

| | Standard device | Standard device (CHF) | Standard device | Standard device (CHF) | New technology device in “MAX EFF” |
|---|---|---|---|---|---|
| Freezer | A + + | 1731 | A + + + | 2160 | 2160 |
| Refrigerators | A + + | 2571 | A + + + | 3135 | 3135 |
| Tumble driers | A + | 1989 | A + + + | 3275 | 3275 |
| Washing machines | A + | 1355 | A + + + | 2697 | 2697 |
| Dishwasher | A + | 1989 | A + + + | 3275 | 3275 |
| Ovens | A | 2655 | A + | 3168 | 3168 |

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